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Interim Report for EPA/EMA Cooperative Test Program

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16. ABSTRACT

The Engine Manufacturers Association/Environmental Protection Agency (EMA/EPA) cooperative test program was initiated in May 1981 to analyze lab-to-lab variability in particulate emission measurements and to assess whether or not the large amount of transient emissions data generated at the Southwest Research Institute (SwRI) was repeatable at other laboratories. The program also was designed to determine ways to improve repeatability. Six engines which are newer models of engines tested under the SwRI baseline program, were chosen to be tested by seven labs: Cummins, Detroit Diesel Allison (DDA), International Harvester (IHC), Caterpillar (CAT), Mack, SwRI, and EPA. A total of 30 sets of tests were scheduled to be conducted on these six engines. Currently 77 percent of these tests have been completed. By June 1, 90 percent of the testing should to be complete, and the program will be completed by July 1, 1982.

This report will analyze all of the data currently available. First, inter-lab variability will be discussed, followed by a discussion of intra-lab variability. The correlation between 13-mode and transient particulate emissions will not be presented in this report due to the limited amount of data available, but will be reviewed in the final report.

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By

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Technical Reports do not necessarily represent final EPA decisions or positions. They are intended to present technical analysis of issues using data which are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments which may form the basis for a final EPA decision, position or regulatory action.

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I. Introduction

The Engine Manufacturers Association/Environmental Protection Agency (EMA/EPA) cooperative test program was initiated in May 1981 to analyze lab-to-lab variability in particulate emission measurements and to assess whether or not the large amount of transient emissions data generated at the Southwest Research Institute (SwRI) was repeatable at other laboratories. The program also was designed to determine ways to improve repeatability. Six engines which are newer models of engines tested under the SwRI baseline program, were chosen to be tested by seven labs: Cummins, Detroit Diesel Allison (DDA), International Harvester (IHC), Caterpillar (CAT), Mack, SwRI, and EPA. Table 1 presents the test plan for these engines. A total of 30 sets of tests were scheduled to be conducted on these six engines. Currently 77 percent of these tests have been completed. By June 1, 90 percent of the testing should to be complete, and the program will be completed by July 1,1982.

This report will analyze all of the data currently available. First, inter-lab variability will be discussed, followed by a discussion of intra-lab variability. The correlation between 13-mode and transient particulate emissions will not be presented in this report due to the limited amount of data available, but will be reviewed in the final report.

II. Inter-Lab Variability

A. Transient Testing

Tables 2-4 present composite, cold start and hot start emission results for particulate, HC and NOx. Each lab conducted at least 2 cold starts and 12 hot starts per engine. The inter-lab variability ($s/\bar{x}$) has been calculated for only those engines which have been tested by more than two labs. Overall, the particulate, HC and NOx variability has been quite acceptable at less than 10 percent with the exception of the Mack engine which has exhibited signs of variability not associated with inter-lab variability trends. Composite, cold start, and hot start variability are comparable, with NOx emission measurement appearing to have the least variability. Initially, it was expected that there would be much inter-lab variability for transient particulate emissions. However, an examination of the data to date does not bear this out.

The greatest variability for the HC emissions occurred with the Mack and Cummins engines. The first set of data reported by EPA for the Cummins engine was excluded from the inter-lab variability calculations because during testing by EPA the engine unknowingly developed a turbocharger oil leak. This leak was found by DDA during their testing subsequent to EPA testing. It is possible that HC results from the other test sites were affected by this leak; this could be the reason for the high variability for this engine. The engine completed a series of transient and 13-mode

tests at EPA, with a replacement turbocharger installed, to verify the above contention and has been shipped to Cummins for testing.

The variability of the Mack engine has been reviewed in an earlier report and will not be discussed in this interim report.

In addition to transient composite and 13-mode steady-state emission results, Tables 2 and 5 also include normalized data. The data was normalized by dividing each laboratory's emission result by the mean value for the engine. Then the coefficient of variation ($s/\bar{x}$) for all of the normalized composite and 13-mode data was calculated. This coefficient of variation is an indication of the degree of inter-lab variability associated with the measurement of each emission. The overall variabilities for the composite particulate, HC and NOx emission measurements are 8.7, 12.6, and 9.2 percent, respectively.

B. Steady-State Testing

The steady-state testing included NOx, HC and particulate sampling over the 13-mode test and particulate sampling for modes 6 and 11 of the 13-mode test. These results are presented in Table 5. In most cases results at each lab represent at least 2 tests. Once again the inter-lab variability for the Cummins engine's HC and particulate emissions may have been high due to the effect of the turbocharger oil leak.

The overall variability for the 13-mode particulate, HC and NOx emission values are 16.7, 8.3 and 7.7 percent, respectively. When comparing 13-mode and transient particulate emissions, it is evident that the variability is 10 percent greater for the 13-mode test. The variabilities between 13-mode and transient NOx and HC emission measurements are approximately the same.

III. Intra-Lab Variability

Table 6 presents intra-lab variability for transient HC, NOx and particulate emissions. The intra-lab variability for each lab is expressed as the standard deviation divided by the mean, ($s/\bar{x}$). The variability of NOx emission measurements is excellent, ranging from 1.0 to 6.8 percent. Variability of HC measurement ranges from 0.9 to 16.9 percent, while particulate measurements range from 2.3 to 10 percent

IV. Summary

In summary, 73 percent of the testing from the EMA/EPA cooperative test program has been completed. Six engines are involved in this test program and are being tested by seven different laboratories. Inter-lab variability for both transient and 13-mode testing has been below 10 percent except for 13-mode particulate which was on the order of 16.7 percent, and transient HC at 13 percent. The NOx measurement appears to have the least variability. When comparing 13-mode particulate emissions with transient emissions, it appears that inter-lab variability is greater for the 13-mode particulate emission. Variability between 13-mode and transient HC and NOx emissions are about the same.

Intra-lab variability for NOx emission measurement was excellent, averaging 3.3 percent. Intra-lab variability for HC and particulate emissions are comparable with the average variability for HC being 6.1 percent, and for particulate, 4.1 percent.

References

1. "Diesel Hydrocarbon and Particulate Correlation Status," Danyko, D., EPA, August 14, 1981.

Table 1

Test Plan for EMA/EPA Cooperative Engine Test Program

Test Engine	Test Site							No. of Test Sets Per Engine
	SwRI	IHC	CAT	CUM	MACK	DDA	EPA	
IHC DTI-466B	8/81	7/81 (5/82)	11/81	3/82 (6/82)	9/81	2/82	(4/82)	9
CAT 3406 DITA			8/81 3/82	10/81				3
CAT 3208 DINA		8/81	4/81 5/82					3
Cummins VTB-903	5/81			4/81 (5/82)		11/81	9/81 (3/82*)	6
Mack ETSA-676			10/81		7/81 (4/82)		2/82	4
DDA 8V-71TA	8/81		5/82	9/81	1/82	6/81 (6/82)		6
Engines Per Lab.	3	2	5	4	3	3	3	31

* Retest at EPA due to turbocharger malfunction.
X/XX Date tests completed.
(X/XX) Date tests estimated to be completed.

Table 2

EMA/EPA Cooperative Test Program

Transient Composite Emission Results (g/bhp-hr)

Test Engine	Particulate		HC		NOx	
	x[1]	$x/\bar{x}$[2]	x	$x/\bar{x}$	x	$x/\bar{x}$
1. Cummins VTB-903						
Lab: Cummins	0.67	1.02	1.69	0.86	5.63	1.07
SwRI	0.67	1.02	2.24	1.14	5.57	1.06
EPA	0.63	0.95	2.01	1.03	4.92	0.94
DDA	0.65	0.98	1.91	0.98	4.87	0.91
$\bar{x}$	0.66		1.96		5.25	
$s/\bar{x}$, %	2.9		11.6		7.8	
2. Mack ETSA676						
Lab: Mack	0.71	1.04	0.85	1.18	6.32	0.74
Caterpillar	0.53	0.78	0.73	1.01	6.82	0.94
EPA	0.81	1.19	0.57	0.79	8.54	1.18
$\bar{x}$	0.68		0.72		7.23	
$s/\bar{x}$, %	20.8		19.6		16.1	
3. IH DTI-466B						
Lab: IHC	0.74	1.10	0.99	1.05	3.86	0.93
SwRI	0.63	0.94	0.87	0.93	4.41	1.06
Mack	0.64	0.96	0.91	0.97	3.97	0.95
Caterpillar	-	-	0.99	1.05	4.44	1.06
$\bar{x}$	0.67		0.94		4.17	
$s/\bar{x}$, %	9.1		6.4		7.1	
4. Cat 3208 DINA						
Lab: Caterpillar	0.68	1.00	0.95	0.83	7.95	1.02
IHC	0.68	1.00	1.32	1.16	7.66	0.98
$\bar{x}$	0.68		1.14		7.81	
5. Cat 3406 DITA						
Lab: Caterpillar	0.76	1.00	0.58	1.18	4.7	1.00
Cummins	0.76	1.00	0.39	0.80	4.7	1.00
$\bar{x}$	0.76		0.49		4.7	
6. DDA 8V-71TA						
Lab: DDA	0.48	1.00	0.74	1.07	7.38	0.95
SwRI	0.44	0.92	0.63	0.91	7.91	1.02
Cummins	0.53	1.10	0.69	1.00	7.90	1.02
$\bar{x}$	0.48		0.69		7.73	
$s/\bar{x}$, %	9.3		8.0		3.9	
Overall Average, $\bar{x}$[3]		1.00		.9967		.9906
$s/\bar{x}$, %, (Inter-lab Variability)		8.7		12.6		9.2

[1] The average emission measurement at a given lab.
[2] Normalized value.
[3] $\bar{x}$ of normalized values.

Table 3

EMA/EPA Cooperative Test Program

Transient Cold Start Emission Results

Test Engine	Particulate x*	HC x	NOx x
1. Cummins VTB-903			
Lab: Cummins	1.02	2.79	5.68
SwRI	1.02	4.42	4.95
EPA	0.91	3.65	4.74
DDA	0.96	3.41	4.74
$\bar{x}$	0.98	3.57	5.03
$s/\bar{x}$, %	5.3	18.9	8.9
2. Mack ETSA676			
Lab: Mack	0.70	0.99	6.06
Caterpillar	0.66	0.80	7.04
EPA	0.83	0.64	8.80
$\bar{x}$	0.73	0.81	7.30
$s/\bar{x}$, %	8.9	21.6	19.0
3. IH DTI-466B			
Lab: IHC	0.76	1.26	3.87
SwRI	0.63	1.18	4.59
Mack	0.67	1.21	3.93
Caterpillar	-	1.12	4.42
$\bar{x}$	0.69	1.19	4.20
$s/\bar{x}$, %	9.7	4.9	8.5
4. Cat 3208 DINA			
Lab: Caterpillar	0.82	1.25	7.80
IHC	0.73	1.71	7.50
$\bar{x}$	0.78	1.48	7.60
5. Cat 3406 DITA			
Lab: Caterpillar	0.86	0.64	4.64
Cummins	0.75	0.43	5.17
$\bar{x}$	0.80	0.54	4.91
6. DDA 8V-71TA			
Lab: DDA	0.54	0.78	7.22
SwRI	0.45	0.74	6.57
Cumimins	0.51	0.72	7.46
$\bar{x}$	0.50	0.75	7.08
$s/\bar{x}$, %	9.2	4.1	6.5

* x = The average emission measurement at a given lab.

Table 4

EMA/EPA Cooperative Test Program

Transient Hot Start Emission Results

Test Engine	Particulate x*	HC x	NOx x
1. Cummins VTB-903			
Lab: Cummins	0.63	1.50	5.62
SwRI	0.61	1.87	5.70
EPA	0.54	1.60	5.141
DDA	0.58	1.61	5.01
$\bar{x}$	0.59	1.65	5.37
$s/\bar{x}$, %	6.6	9.5	6.4
2. Mack ETSA676			
Lab: Mack	0.66	0.78	6.83
Caterpillar	0.56	0.74	6.68
EPA	0.76	0.56	8.39
$\bar{x}$	0.66	0.69	7.30
s/x, %	15.2	16.9	13.0
3. IH DTI-466B			
Lab: IHC	0.75	0.94	3.86
SwRI	0.63	0.82	4.38
Mack	0.66	0.84	3.96
Caterpillar	-	0.95	4.41
$\bar{x}$	0.68	0.89	4.15
$s/\bar{x}$, %	9.2	7.6	6.8
4. Cat 3208 DINA			
Lab: Caterpillar	0.66	0.92	7.98
IHC	0.70	1.24	7.60
$\bar{x}$	0.68	1.08	7.79
5. Cat 3406 DITA			
Lab: Caterpillar	0.72	0.57	4.74
Cummins	0.77	0.38	4.95
$\bar{x}$	0.75	0.48	4.85
6. DDA 8V-71TA			
Lab: DDA	0.47	0.73	7.41
SwRI	0.44	0.61	6.71
Cummins	0.54	0.69	7.96
$\bar{x}$	0.48	0.68	7.36
$s/\bar{x}$, %	10.6	9.0	8.5

* x = The average emission measurement at a given lab.

Table 5

EMA/EPA Cooperative Test Program

Steady-State Emission Results

Test Engine	13-Mode Particulate		13-Mode HC		13-Mode NOx		Mode-6 Part.		Mode-11 Part.	
	x*	$x/\bar{x}$	x	$\bar{x}/x$	x	$\bar{x}/x$	x	$\bar{x}/x$	x	$\bar{x}/x$
1. Cummins VTB-903										
Lab: Cummins	0.44	1.10	0.81	0.93	6.07	1.03	0.24	0.96	0.72	0.99
SwRI	0.38	0.95	0.95	1.09	6.39	1.08	0.29	1.16	0.77	1.05
EPA	0.44	1.10	0.94	1.06	4.84	0.82	0.25	1.00	0.74	1.00
DDA	0.33	0.83	0.84	0.97	6.36	1.07	0.23	0.92	0.71	0.97
$\bar{x}$	0.40		0.89		5.92		0.25		0.74	
$s/\bar{x}$, %	(13.3)		(8.0)		(12.4)		(10.5)		(3.6)	
2. Mack ETSA676										
Lab: Mack	0.40	0.78	0.58	1.09	6.25	0.88	-	-	-	-
Caterpillar	0.69	1.35	0.52	0.98	8.14	1.15	1.35	-	0.79	-
EPA	0.44	0.86	0.48	0.90	6.83	0.97	1.74		0.50	
$\bar{x}$	0.51		0.53		7.07		1.55		0.65	
$s/\bar{x}$, %	30.8		9.5		13.7					
3. IH DTI-466B										
Lab: IHC	-	-	0.68	0.92	4.14	1.06	-	-	-	-
SwRI	0.53	1.20	0.77	1.04	3.86	0.99	0.51	-	0.95	-
Mack	0.35	0.80	0.86	1.16	3.51	0.90	-	-	-	-
Caterpillar	-	-	0.63	0.85	4.13	1.06	-	-	-	-
$\bar{x}$	0.44		0.74		3.91					
$s/\bar{x}$, %			13.8		7.6					
4. Cat 3208 DINA										
Lab: Caterpillar	0.61	1.22	0.97	1.00	8.13	1.01	0.52	0.88	1.00	1.02
IHC	0.50	0.89	0.97	1.00	7.97	0.99	0.66	1.12	0.96	0.98
$\bar{x}$	0.56		0.97		8.05		0.59		0.98	
5. Cat 3406 DITA										
Lab: Caterpillar	0.72	1.04	0.34	1.03	5.01	1.00	0.98	1.10	1.1	1.04
Cummins	0.66	0.96	0.32	0.97	5.0	1.00	0.79	0.89	1.02	0.96
$\bar{x}$	0.69		0.33		5.0		0.89		1.06	
6. DDA 8V-71TA										
Lab: DDA	0.23	1.05	0.63	1.02	8.73	0.99	0.25	1.09	0.32	0.93
SwRI	0.25	1.14	0.68	1.10	8.97	1.01	0.22	0.96	0.38	1.12
Cummins	0.19	0.86	0.55	0.89	8.88	1.00	0.23	1.00	0.33	1.00
$\bar{x}$	0.22		0.62		8.85		0.23		0.343	
$s/\bar{x}$, %	13.7		10.6		1.6		6.5		9.4	
Overall $\bar{x}$		1.01		1.00		1.01		1.01		1.00
$s/\bar{x}$, %, (Inter-Lab variability)		16.7		8.3		7.7		9.6		5.1

* x = The average emission measurement at a given lab.

Table 6

EMA/EPA Cooperative Test Program

Intra-Lab Variability

Transient Testing

HC Emissions Variability, ($s/\bar{x}$, %)

Test Lab / Test Engine	Cummins	DDA	Cat	Mack	IHC	SwRI	EPA
Cummins		6.8				5.0	0.9
DDA	16.9	1.9				16.4	
Cat 3406	2.4		8.8				
Cat 3208			6.5		4.0		
Mack			2.0	8.5			13.8
IH			3.5	6.9	5.3	3.1	

Particulate Emissions Variability, ($s/\bar{x}$, %)

Test Lab / Test Engine	Cummins	DDA	Cat	Mack	IHC	SwRI	EPA
Cummins		8.6				2.9	3.0
DDA	3.5	3.3				2.3	
Cat 3406	2.6		5.6				
Cat 3208			3.0		10.0		
Mack			10.5	3.0			4.6
IH				6.2	4.0	2.6	

NOx Emissions Variability, ($s/\bar{x}$, %)

Test Lab / Test Engine	Cummins	DDA	Cat	Mack	IHC	SwRI	EPA
Cummins		2.6				3.9	2.9
DDA	1.2	1.2				1.9	
Cat 3406	1.0		1.9				
Cat 3208			3.1		3.8		
Mack			2.3	5.7			6.8
IH			1.9	4.2	4.5	1.5	